Public Health Surveillance: A Tool for Informed Decision Making

For forty years, the US Centers for Disease Control and Prevention (CDC) has helped train more than 18,000 disease detectives in over 80 countries through its Field Epidemiology Training Program (FETP), forming the foundation of global public health surveillance efforts. Indeed, the WHO and the World Bank cited public health surveillance as an essential function of any public health system[1] as countries battled the HIV and severe acute respiratory syndrome (SARS) epidemics. Today the spotlight is especially bright on surveillance efforts as we continue to combat SARS-CoV-2, the virus that causes COVID-19 and is responsible for more than 5 million deaths worldwide.[2]

Public health surveillance is intended to monitor threats to human health through ongoing systematic collection, analysis, and interpretation of data that is subsequently disseminated in a timely manner to epidemiologists and public health officials. Surveillance testing is performed on de-identified specimens, and, thus, results are not linked to individual people. The intent is to guide policy decisions rather than individual patient care plans. At a macro level, surveillance can estimate population-based health status and characterize the behavior of populations to identify the need for interventions. It can also measure the effects of such interventions over time. The end goal of surveillance systems is to empower decision makers to lead and manage more effectively by providing timely, useful evidence.

Objectives of Surveillance Systems

The fundamental principle of public health surveillance is that the surveillance should be designed and implemented to provide fact-based information to decision makers in a timely manner at the lowest possible cost. Public health surveillance provides the scientific and factual data to guide interventions in various scenarios including:

- **Viral/Outbreak surveillance** prevents the spread of acute infectious diseases through swift intervention by addressing the behaviors of a community which increase transmission.
- **Surveillance for biologic terrorism** supports early detection and characterization of an incident of biologic terrorism.
- **Complex emergency surveillance** is needed in response to a natural disaster such as a tsunami and should include analysis of the population's health in three stages: pre-impact, during the disaster and, post-impact.[3]
- **Environmental public health surveillance** which correlates death, disease, injury, and disability with specific environmental hazards and exposures.

---

[1] World Bank. 2001. *World Development Report 2000–2001: Attacking Poverty*. New York: Oxford University Press.
[2] Our World in Data. Statistics: New cases and deaths. www. https://ourworldindata.org/covid-deaths. Updated December 12, 2021.
[3] Binder S and Sanderson LM. The Role of the Epidemiologist in Natural Disasters. *Annals of Emergency Medicine*. 1987;16(9):1081–84.

- **Surveillance in refugee populations** during large-scale relief efforts for displaced people requires ongoing assessments of health needs to address preventable causes of morbidity and mortality.
- **Chronic disease surveillance** offers information essential to development and evaluation of policies for health improvement concerning noncommunicable conditions such as hypertension, excessive alcohol consumption, tobacco use, and obesity.
- **Injury Surveillance** monitors one of the 10 leading causes of death worldwide—injury. Injury surveillance tracks the incidence, causes, and circumstances of fatal and nonfatal injuries.

The Role of Laboratory Surveillance Strategies in Major Outbreaks

It seems incredible that a disease as devastating as AIDS could have spread silently across the globe over many years before it was detected, and before effective control measures were implemented in the 1980s. In recent years, surveillance and response systems have improved and more effectively identify and prevent the spread of infectious diseases.

Traditional surveillance systems, developed over the past 40 years included sentinel system that gathered reports from prearranged sources for defined conditions seeking patterns that might indicate trending health problems among a target population.[4] For example, a sentinel surveillance network may engage private practitioners in reporting cases of influenza. Another approach was population-based surveys repeated on a regular basis.[5] Population-based surveys, like those deployed for HIV-prevalence, require the use of standard protocols, supervision of interviewers, comparable sampling strategy, and standard questionnaires.

Recent times have seen the increasing dominance of laboratory-based surveillance in public health initiatives. This method has long been the gold standard for identifying foodborne disease by sampling patients with acute gastroenteritis to identify microbiologic diagnoses. For bacterial pathogens such as *Salmonella*, determining the serotype of the strains in central reference laboratories allows rapid and complete identification of foodborne epidemics in advance of preventable death and disability.[6]

Pooled Specimen Surveillance

The closure of schools is a severe adverse effect of viral outbreaks. Other than negatively affecting learning aptitude, school closures have been linked to several psychosocial problems,[7] inadequate nutrition, and increasing socioeconomic inequality. To remain open, schools must develop a means to continually monitor their students and staff for active virus. Applying a cost-effective surveillance method used during the HIV epidemic[8] and to monitor blood donations for hepatitis,[9] many schools pool samples to increase the number of people tested with fewer PCR tests. Pooled samples can enable

[4] Birkhead, GS and Maylahn CM. "State and Local Public Health Surveillance." In *Principles and Practices of Public Health Surveillance,* ed. S. M. Teutsch and R. E. Churchill, 270. New York: Oxford University Press. 2000.
[5] Thacker SB and Berkelman RL. Public Health Surveillance in the United States. Epidemiologic Reviews. 1988;10:164–90.
[6] Herikstad H, Motarjemi Y, Tauxe RV. Salmonella Surveillance: A Global Survey of Public Health Serotyping. Epidemiology and Infection. 2002;129(1):1–8.
[7] Petretto DR, Masala I, Masala C. School closure and children in the outbreak of COVID-19. Clin Pract Epidemiol Ment Health. 2020; 16: 189-191
[8] Tamashiro H, Maskill W, Emmanuel J, Fauquex A, Sato P, Heymann D. Reducing the cost of HIV antibody testing. *Lancet*. 1993; 342: 87-90
[9] Roth WK, Weber M, Seifried E. Feasibility and efficacy of routine PCR screening of blood donations for hepatitis C virus, hepatitis B virus, and HIV-1 in a blood-bank setting. *Lancet*. 1999; 353: 359-363

routine large-scale surveillance without stressing laboratory capacity while keeping the maximum number of children in school.

Seroprevalence surveillance

Public health officials have used this method of surveillance testing to randomly select and sample a percentage of all people in a community on a rolling basis to assess local infection rates and trends. Detection of antibodies to SARS-CoV-2 in a person's blood indicates that they were infected at some point. Thus, serologic assays can be used to provide population-based estimates of infection that include people who had mild or asymptomatic infection or who were never tested despite having symptoms. Tracking population seroprevalence over time, in a variety of specific geographic sites, can unveil models of virus transmission and inform policy decisions regarding the use of preventive measures such as mask wearing and social distancing. Seroprevalence surveys can also look at risk factors for disease, such as a person's age, location, or underlying health conditions. Finally, some kinds of seroprevalence surveys can determine how long antibodies provide post-infection antibody protection.

In the Spring of 2020, initial seroprevalence estimates[10] suggested that the number of infections was much greater than reported cases. Therefore, the CDC formed a collaboration of state, local, territorial, academic, and commercial partners to conduct nationwide laboratory-based assessment of SARS-CoV-2 seroprevalence in blood donors with the goals of understanding the percentage of Americans who have antibodies against SARS-CoV-2, and to track how this percentage changes over time.[11] Since July 2020, about 2,000 anonymous blood donation samples per month from each of the 50 States have been collected and tested. The survey is scheduled to continue until January 2022 to inform our understanding of the epidemiology of COVID-19.

Wastewater Surveillance

Although it is most common for laboratory-based surveillance systems to collect samples from sentinel points—such as the blood donation centers mentioned above, a novel collection method for viral surveillance has been employed throughout the COVID pandemic in the US. Wastewater from households or buildings (i.e., toilets, showers, sinks) that can contain human fecal waste can be tested for RNA from SARS-CoV-2. Data from wastewater testing are not meant to replace other COVID-19 surveillance systems but have proven highly effective within institutes of higher education to monitor student populations in co-habitation environments such as dormitories. When the virus is detected, screening tests may be used to identify active cases and invoke quarantine protocols for exposed individuals.

Variant Surveillance

Through the advancement and increased scalability of genomic laboratory resources, molecular subtyping has expanded the potential for laboratory-based surveillance to detect outbreaks by distinguishing the molecular "fingerprint" of an outbreak strain. The US National SARS-CoV-2 Strain Surveillance (NS3) system collects, analyzes, and shares information about the genetic diversity of SARS-CoV-2. Genomic sequence data from CDC, public health laboratories, and commercial laboratories are amassed to track virus evolution and identify emerging variants that may be vaccine resistant, affect

---

[10] Havers FP et al. "Seroprevalence of Antibodies to SARS-CoV-2 in 10 Sites in the United States, March 23-May 12, 2020." *JAMA internal medicine*, 10.1001/jamainternmed.2020.4130. 21 Jul. 2020
[11] Centers for Disease Control and Prevention. Multistate Assessment of SARS-CoV-2 Seroprevalence in Blood Donors. https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/blood-bank-serosurvey.html. Updated Nov. 13, 2020.

the performance of diagnostics or therapeutics, and demonstrate more aggressive transmissibility or severity of illness.

In the CDC-sponsored program, four large airports began the use of large-scale asymptomatic group testing infrastructure with an in-airport testing platform to monitor travelers for COVID-19 and its variants. Viral sequencing is then performed on positive test samples allowing rapid notification of public health officials concerning changes with the virus.[12]

Surveillance of Breakthrough Cases

Although COVID-19 vaccines have been highly effective in slowing the transmission of the virus, they are not perfect. Breakthrough infections among fully vaccinated persons do occur but at a very low rate.[13] For instance, in a study at Rockefeller University between January 21, 2021, and March 17, 2021, a fully vaccinated cohort of 417 individuals had positive PCR screening test results and symptomatic disease at a rate of 0.48% during that period.[14] To monitor these cases, albeit rare, CDC is focusing its surveillance efforts on breakthrough infections that result in hospitalizations or deaths,[15] although some public health officials are advocating for a broader surveillance of all symptomatic breakthrough cases.[16]

Surveillance Information Technology

The collection of surveillance data is of little use without knowledgeable technical personnel conducting regular review to ensure data validity and timely dissemination of actionable information to those who make policy and implement intervention programs. The power of public health surveillance is continually enhanced by the evolution of informatics systems, which enable better collection, standardization, storage, retrieval, analysis, and presentation of large amounts of health data. Data standardization allows for trending of surveillance information over time, across different surveillance approaches, and across countries and regions.

Information technology (IT) and informatics support the realization of effective surveillance systems. Specifically, IT facilitates the collection, analysis, and use of surveillance data where data standards are defined, and system interoperability is established. In these environments, data collection for surveillance can be an automatic by-product of the electronic health record (EHR) used to support clinical care. Under this scenario, electronic notifications can be automatically sent to public health agencies with information about a health event (for example, death, disease, or injury), including all relevant information from the EHR about the patient.

Cell phone-based systems also accelerate collection of key data as does software that is Web-enabled with geographic information systems and global positioning devices. Cloud computing further enables anyone with Internet access to potentially apply the latest version of software running on a distant server to local data to generate up-to-date maps and graphs describing health status in that area.

---

[12] PR Newswire. Concentric by Ginkgo Confirms Detection of Omicron Variant through COVID-19 Air Travel Biosecurity Collaboration with CDC and and XpresCheck. December 7, 2021

[13] Willyard C. Some vaccinated people are still getting COVID: here's why you shouldn't worry. MIT Technology Review. Accessed June 21, 2021.
https://www.technologyreview.com/2021/04/29/1024301/vaccines-covid-breakthrough-infections-immunity-cdc/

[14] Hacisuleyman E, Hale C, Saito Y, et al. Vaccine breakthrough infections with SARS-CoV-2 variants. N Engl J Med. 2021;384(23):2212-2218.

[15] Centers for Disease Control and Prevention. COVID-19 breakthrough case investigations and reporting. Accessed June 22, 2021. https://www.cdc.gov/vaccines/covid-19/health-departments/breakthrough-cases.html

[16] Holtgrave DR, Vermund SH, Wen LS. Potential Benefits of Expanded COVID-19 Surveillance in the US. JAMA. 2021;326(5):381–382.

Furthermore, sophisticated algorithms can trigger when and how an alert should be sent to local, national, or even international health officials. Increasingly sophisticated visual display techniques and creation of customized dashboards of data relevant to specific audiences facilitate timely action by public health officials.

Economics of Public Health Surveillance Systems

The economic crisis that has resulted from countries closing their borders and issuing travel bans, abandoning in-person learning and business activities, imposing strict quarantines, and more,[17] is estimated to have contributed to almost 2.96 trillion US dollars of lost economic output in 2020. The forecasted loss for 2021 is even higher.[18] Although the private sector benefits, it lacks the incentive to invest in public health surveillance systems, and even within national borders, difficult-to-measure benefits for individual communities can lead local authorities to undervalue diligent surveillance. For this reason, funding by the national government is the most prevalent model. Yet, developing countries that lack both the resources and the political will to finance the surveillance systems, tend to be the weak link in global surveillance, although they bear the greatest burden of disease.[19] It is for this reason that independent collaborations such as the Rockefeller Foundation's Pandemic Prevention Institute (PPI) form to augment funding for global data collection and sharing and to improve speed and scope of sequencing in the U.S., Africa, and India.[20]

At a minimum, a cost-benefit analysis of a viral surveillance program must consider testing costs, societal costs from isolations, money saved from hospitalizations averted, and monetized value of lives saved.[21] With these costs, and given expenditures on specific health interventions or programs, one can, by using traditional econometric tools, apply health outcomes data from surveillance systems to achieve a return-on-investment calculation.

Conclusion

Public health surveillance is an essential tool to effectively and efficiently allocate resources and manage public health interventions. Surveillance systems are useful in assessing numerous threats to society, from injury to foodborne disease, chronic conditions, and viral outbreak. Laboratory surveillance has taken on an increasingly prominent role in public health efforts as genomic laboratory resources have become more scalable and novel approaches to specimen collection emerged for timely, accurate, and affordable surveillance of large populations. In a time when we remain confronted by the dire consequences of COVID-19, the innovation and integration of global public health surveillance networks with the latest advances in laboratory surveillance techniques and information technology are central to putting society back on the path to normalcy.

---

[17] Schröder I. COVID-19: a risk assessment perspective. J Chem Health Saf (2020).
[18] Szmigiera M. Impact of the coronavirus pandemic on the global economy - Statistics & Facts Statista.com. Nov 23, 2021. https://www.statista.com/topics/6139/covid-19-impact-on-the-global-economy/#dossierKeyfigures
[19] U.S. GAO (U.S. General Accounting Office). 2001. *Challenges in Improving Infectious Disease Surveillance Systems*. GAO-01-722. Washington, DC: U.S. General Accounting Office.
[20] The Rockefeller Foundation. https://www.rockefellerfoundation.org/pandemicpreventioninstitute/
[21] U.S. Department of Transportation. Revised Departmental Guidance on Valuation of a Statistical Life in Economic Analysis. https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20a%20Statistical%20Life%20Guidance.pdf